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RESEARCH ARTICLE

BIM-based environmental and microclimate analysis from UAV imagery and laser scanning for agrifood building management

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Abstract

This study presents a comprehensive framework for evaluating the structural and environmental performance of food related buildings, validated by applying it to an olive mill (OM) as a case study in southern Italy. The methodology employed Uncrewed Aerial Vehicle (UAV) imagery and laser scanning to generate a precise Building Information Model (BIM) of the structure, that was the base on which a Life Cycle Assessment (LCA) was carried out to evaluate the environmental impact at first level, then a microclimate evaluation was also conducted to study the interaction of the building with its close external environment. The results show that the proposed framework illustrates an efficient methodology for evaluating structures within the food sector through the integration of UAVs, laser scanning, BIM, and environmental analysis software. Through this study, OM buildings have been proved to be also impactful to the environment along with the agricultural and production phases of the olive oil production cycle, underscoring therefore the important need to integrate structural performance into sustainability evaluations. Significant embodied emissions associated with construction and maintenance have been identified by the LCA, while substantial heat island effects were reported by microclimate evaluation. The obtained results also were compared to a previous evaluation of the same building by the LEED green building assessment tool and the results revealed inconsistencies between both evaluations, underscoring the need to integrate digital technologies and advanced modeling into green building assessment frameworks.

Keywords BIM · UAV · Laser scanning · Life cycle assessment · Microclimate analysis · Olive mill

Abbreviations

BIM	Building Information Modeling
FOV	Field Of View
GIS	Geographic Information Systems
GWP	Global Warming Potential
GSD	Ground Sampling Distance
HS	Hand-held Scanner
IMU	Inertial Measurement Unit
LiDAR	Light Detection And Ranging
LCA	Life Cycle Assessment
LCImA	Life Cycle Impact Assessment
LCInA	Life Cycle Inventory
LOIN	Level Of Information Need
LOD	Level Of Development
OM	Olive Mill
PCM	Phase Changing Material
TLS	Terrestrial Laser Scan
UAV	Uncrewed Aerial Vehicle

1 Introduction

The substantial contribution of new technologies has significantly influenced several sectors worldwide such as the construction industry. Nevertheless, this sector is undeniably backward when it comes to implementing these technologies, especially on operational buildings. In order to address the weaknesses of older buildings and to include them in the climate change resilience and adaptation approaches, the use of innovative technologies helps accomplishing this task [1, 2]. In fact, Building Information Modeling (BIM) has revolutionized the construction industry by overcoming the limitations of traditional construction practices. By providing

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a comprehensive digital representation of buildings, BIM facilitates the efficient management of construction processes and performance throughout the entire lifecycle of a structure. This approach enables precise tracking of individual building components, enhances decision-making, and supports sustainability initiatives by optimizing resource use, minimizing environmental impact, and improving overall efficiency in the built environment [3–5]. Nevertheless, the sector ranks among the least digitized ones globally, leading to increased project management complexity, avoidable inefficiencies, and time consumption [6]. Despite the transformative potential of BIM, its adoption varies significantly across the globe. While some developed and developing countries have successfully integrated BIM into their construction practices, others remain hesitant to transition from traditional methods [7, 8]. Some key obstacles to widespread adoption that have been underscored are the limited awareness and understanding of BIM's capabilities within the industry, high initial costs, time constraints, and insufficient access to information about the building [7]. In fact, the increase of BIM use is majorly noticed during the design phase of constructions, while for existing buildings, this technology is yet to be expanded due to lack of data about the building and its evolution [9]. Actually, regarding the maintenance, repair, and assessment of a building, a BIM model should be as accurate as possible in representing each component. This high level of structural accuracy enables the facility managers and engineers to identify potential issues, plan interventions, and execute repairs with minimal disruption [10, 11]. This issue has been the focus of numerous research initiatives. To address the challenges posed by outdated or incomplete documentation, advanced surveying technologies, including laser scanning and photogrammetry, have been increasingly adopted [12]. These methods facilitate the precise capture of existing building geometries, thereby enriching BIM models with more comprehensive information. By integrating high-resolution point cloud data into the BIM workflow, these methods facilitate the creation of detailed digital models, improving decision-making in design, renovation, and sustainability assessments [6, 13]. In fact, this technology had been involved deeply in building assessment and helped many project holders decide on the level of sustainability of different kinds of buildings, throughout their life cycle [14].

Regarding the environmental assessment of operational buildings, several frameworks suggest the integration of BIM models and different evaluation methods such as Life Cycle Assessment (LCA) [15], Internet of Things (IoT) [16], real-time monitoring algorithms [17], etc. On the other hand, the ongoing global shift toward urbanization, coupled with the accelerating impacts of climate change, has intensified the need to investigate strategies for mitigating the detrimental effects of extreme microclimatic conditions on urban functioning, particularly in relation to building energy use and public health. Over the past decade, the Urban Heat Island (UHI) phenomenon has exhibited increasingly pronounced intensities, substantially influencing pedestrian thermal comfort, perceived air quality, and the energy demand of buildings within compact urban settings [4].

In Italy, many olive mills (OMs), often centuries old, were originally built using traditional construction methods that reflected the agricultural and architectural practices of their time. Over the years, these mills have undergone numerous, often unplanned renovations, adapting to advances in olive oil production processes, shifts in agricultural needs, and changing technologies. These modifications, frequently undertaken without formal documentation or updates to the original floor plans, result in a lack of standardized records or accurate structural planimetry. Consequently, this absence of documentation creates significant challenges for modelers attempting to digitally reconstruct these mills by BIM, as they struggle to capture the exact layout and materials of the altered structures.

Additionally, the difficulties in gathering reliable data on these structures limit the scope of sustainability assessments. As these olive mills form a crucial part of the Mediterranean's cultural and agricultural heritage, an accurate sustainability assessment could inform preservation and modernization efforts, guiding resource efficiency and environmental impact reduction. Nevertheless, without detailed digital models, evaluating their energy efficiency, material lifecycle, or potential for renewable integration becomes complex, thereby hindering efforts to support their conservation in a sustainable manner.

1.1 Scan-to-BIM and photogrammetry use in construction

The use of Laser scanning has been reported since 1980, where it was applied in different sectors particularly in construction [18]. Since then, the scan-to-BIM process, which relies on point clouds generated via 3D laser scanning and/or aerial photogrammetry have been the subject of much research. A study by Skrzypczak I. et al. in 2022 [19] involves the 3D modeling of three different facilities located in Poland: a utility/laboratory building, a sports facility, and a sports hall. Data was acquired using a Faro Focus 3D laser scanner. To facilitate the modeling of the sports hall's roof, close-range photogrammetry by an uncrewed aerial vehicle (UAV) was utilized. The study compared the model created with the real building by direct geometry measurements and the analysis revealed a measurement accuracy of ± 1 cm. Moreover, a study by Jiang, Z. et al. in 2022 [20] highlighted the importance of introducing digital technologies to monitor construction progress in real-time and minimize project delay and its effects. The study uses a combination of methods including 3D scanning technology to track the progress of road bridges construction, and the results showed that the proposed framework can effectively monitor the geometric increment of road bridges construction projects, with an accuracy of less than 5% difference between as-built and as-design volumes. Furthermore, a case study carried out by Sing, M.C. et al. in 2022 [21] over a 62-year-old tenement building, aimed to generate quantity take-offs for estimating building maintenance costs by means of Terrestrial Laser Scan (TLS) and BIM. The findings revealed the practicality of adopting the Scan-To-BIM technique to significantly minimize time and cost in collecting data about the building blocks and their state. Subsequently, with technological advancements and innovations, the use of UAVs has emerged to facilitate the previously described processes by redefining the construction projects planification, execution, evaluation and maintenance [22]. In a study carried out by Praticò et al. in 2023[12], surveys with TLS, Hand-held Scanner (HS) and UAV were integrated to obtain a complete 3D point cloud to serve as basis to BIM production of agrifood buildings. Three different olive oil mills were surveyed and accuracy of 3D point clouds generated by TLS, HS and UAV were tested using the multi-scale model to model cloud comparison (M3C2) obtaining a maximum distance of 0.06 m between the analyzed clouds [23].

UAVs, enhanced with advanced high-resolution cameras and LiDAR (light detection and ranging) sensors, play a crucial role in enabling highly accurate mapping, detailed topography analysis, and efficient site planning. UAV images joined with digital image processing, as they can be combined with other technologies, such as Geographic Information Systems (GIS), AutoCAD and BIM, have been widely used in the construction industry [24]. In fact, in a work carried out by Seongdeok Bang et al. [25] in 2017, a construction site was monitored by means of UAV, accompanied by a preprocessing method aiming to enhance the resolution for accurate image stitching. Another study by Hyunjun Kim et al. in 2017 [26] employed a UAV incorporating hybrid image processing to identify the concrete cracks on buildings.

1.2 Life cycle assessment and microclimate evaluation of buildings

The environmental assessment of buildings has undergone thorough studies to examine the influence of structures, enhance their efficiency, and analyze their interaction with the surrounding environment, both indoors and outdoors. Conducting an LCA is one of the commonly used methods to estimate the environmental impact of buildings and help choose appropriate building materials with acceptable costs. This was demonstrated by a work of Najjar et al. in 2019 [27], in which researchers associated the BIM of a residential structure to an LCA, in order to choose the best envelope that ameliorates the building efficiency on energy, carbon emissions, and cost. After optimizing the framework and comparing it to a baseline design, the findings reveal that the approach helps improve the building performance by approximately 40% on average. Other research routed for LCA to compare carbon emissions levels of buildings life stages such as a study by C. Peng in 2016 [28].

On the other hand, given the continuous and reciprocal interaction between climatic conditions and the built environment, microclimate analysis has been indispensable. It provides a robust basis for architectural decisions concerning building morphology and design, while also enabling rigorous evaluation of how buildings impact surrounding airflow, energy fluxes, and occupants' thermal comfort [29]. Several research has been conducted on this matter, with a special focus on cities and neighborhoods. A work of T. Hong et al. in 2021 [30] examines the influence of the urban microclimate on buildings regarding energy consumption, peak demand, indoor conditions during extreme events, and resilience, in the downtown and urban-core areas of San Francisco, California. The study used ten years of hourly meteorological data from multiple regional monitoring sites. It localized heat-islands in the area and offered insights into city planning and dense-urban building design, while emphasizing the need for more refined climate data and microclimate analyses to improve building performance and energy efficiency. On the other hand, other microclimate studies were conducted to seek alternatives capable of mitigating the heat island effect in cities [31, 32], or urban parks [33, 34], such as implementing more green zones, blue infrastructure, etc. To conduct microclimate analysis, several tools are now available. A study of G. M. Stavrakakis et al. in 2021 [17] gives an overview of the commonly used programs for microclimate analysis namely: Rayman, Solweig, TEB, ENVI-met, etc., and highlights the specificity of each.

1.3 Aim and scope

Reconstructing an accurate 3D model of an existing building remains a complex challenge, particularly for older structures that have undergone extensive renovations. In many cases, available planimetric documentation reflects only the original construction, lacking updates that account for subsequent modifications. These limitations hinder accurate assessments of a building's current state.

To address these challenges, this study presents an advanced, integrated workflow that combines BIM, laser scanning, and UAV imagery. This approach enhances the precision of digital reconstruction by capturing reliable geometric and material details. The resulting 3D model serves as a foundation for the building assessment, including an LCA, then a microclimate analysis. These two assessments are complementary since they give a wholistic reasoning on the environmental impact of the construction properties, in terms of carbon emissions and heat island effect. The microclimate assessment can serve not only in urban contexts, but also in open landscapes where individual buildings can impact the local climate conditions. Furthermore, this research can provide insights about the inside atmosphere of the structure in relation to the outer environment.

On the other hand, the proposed methodology was tested in an OM for several reasons. First, the significant presence of this kind of structure across the Mediterranean basin. The region accounts for approximately 90% of global olive oil production, and the massive spread of OMs highlights the importance of assessing their performance from an environmental standpoint. Actually, while most existing evaluations focus primarily on production efficiency or agricultural outputs, the building envelope and its environmental impact are often missed. Second, this study addresses this gap by focusing on the structural footprint of OMs and their influence on the local microclimate. The objective is to explore potential retrofitting strategies that could enhance environmental performance and resilience, particularly in the context of climate change adaptation.

2 Materials and methods

To leverage the advantages of BIM in projects involving existing buildings, it is first necessary to create an accurate digital representation of the structure. This was achieved through the scan-to-BIM process, which relies on point clouds generated via 3D laser scanning and aerial photogrammetry. In fact, Laser scanning is the most effective method for capturing the indoor environment of a building with high precision [35]. On the other hand, documenting exterior features, particularly the roof, can be challenging. Therefore, aerial photogrammetry was used as a complementary solution to generate a holistic representation of the building roofs.

The laser-scanned point cloud may be co-registered with the aerial point cloud by utilizing common reference points, namely scanning targets for laser data and ground control points for aerial imaging [20, 36]. In this study, the laser-scanned point cloud was imported into Autodesk ReCap Pro which allowed the transfer of the real time representation of the building to REVIT, while the UAV images were reconstructed and used as reference for the roofs. The BIM model was built and served subsequently to conduct two building assessments: an LCA, and a microclimate analysis. This framework, summarized in Fig. 1, constitutes an easy holistic approach to evaluating existing buildings in real time and in a completely digital way.

2.1 Study site

The OM investigated in this study is named "Cooperativa Olearia Delia" and is located in Scido, a municipality within the province of Reggio Calabria, southern Italy (latitude 38°15'36.1" N, longitude 15°56'28.6" E – Fig. 2a). The facility spans a total area of 10,132.63 m² and comprises several functional zones (Administration, operations areas, storage room), which were completed by 2000. Subsequent expansions included the installation of standing seam roofs across all administrative and operational zones, along with the addition of parking areas and a paved courtyard (Fig. 2b).

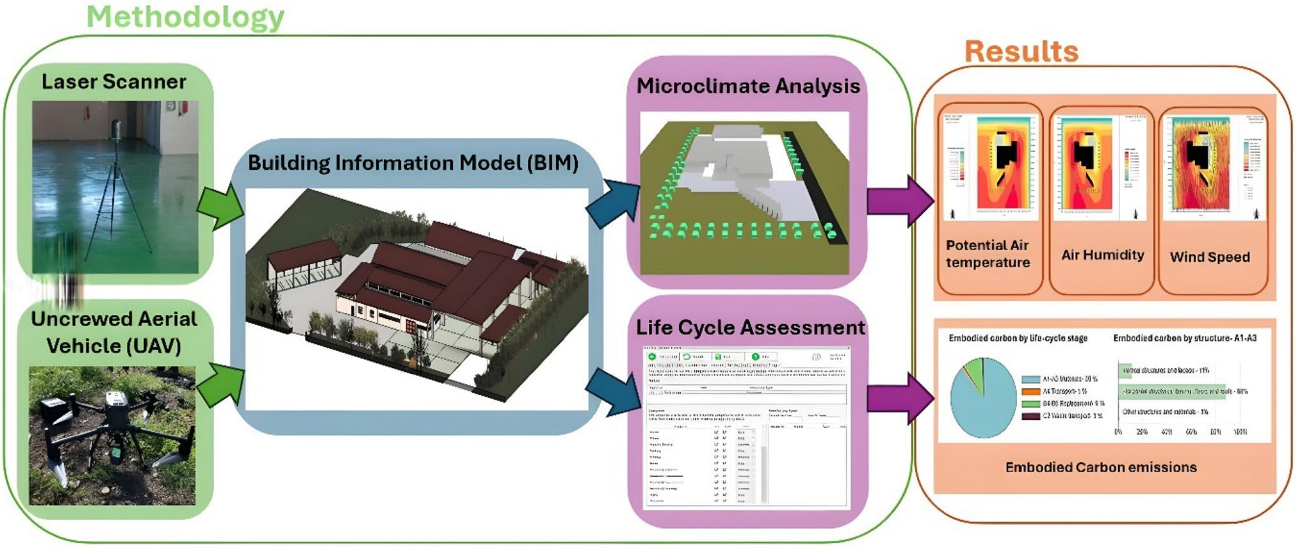

Fig. 1 Workflow of the methodology implemented in four main phases: Laser Scanning LiDAR and UAV survey (in green), Building Information Model (BIM) development (in blue), microclimate analysis and Life Cycle Assessment (LCA) (in purple), and results (in orange)

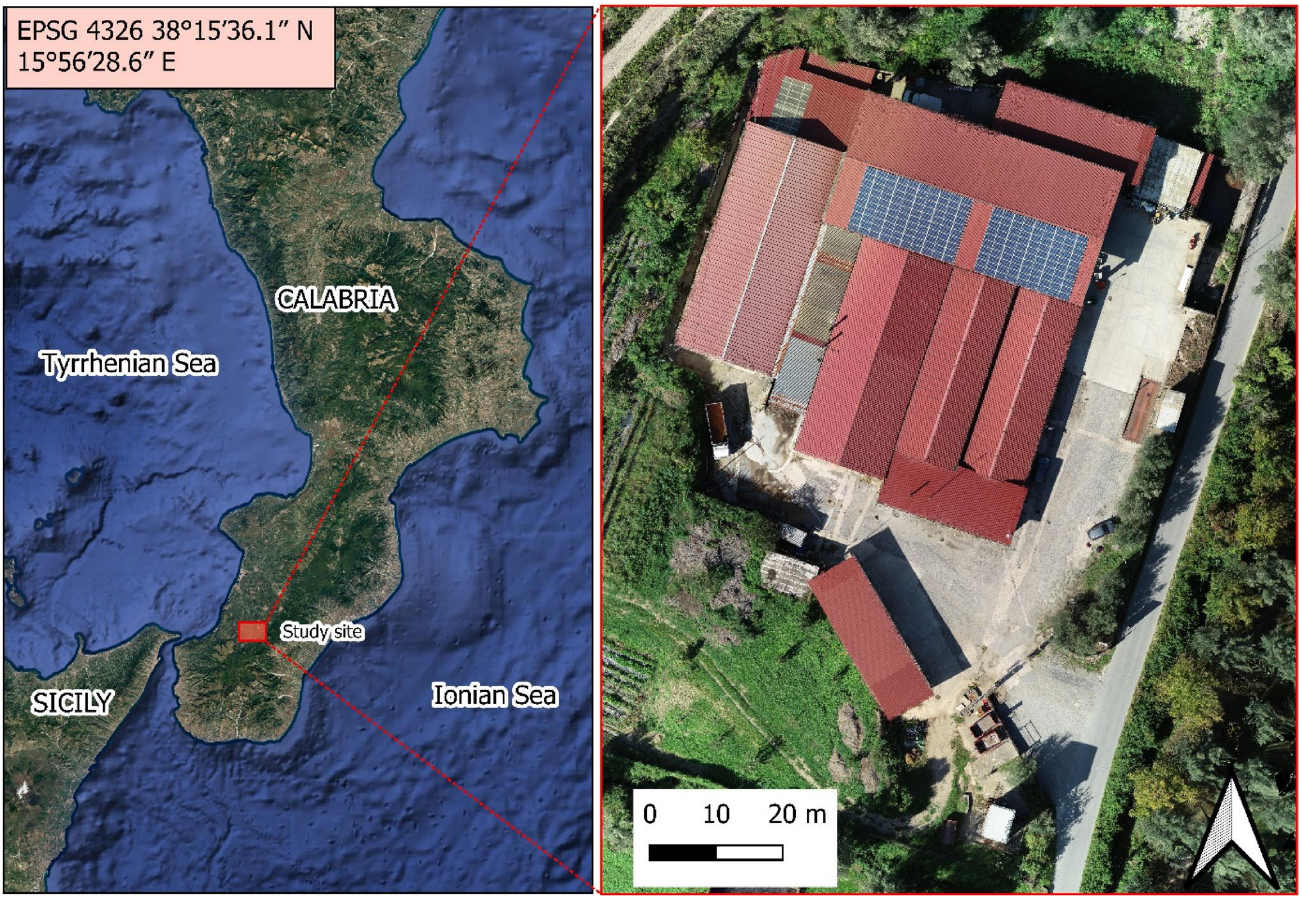

Fig. 2 **a-b**. Location of the study site in the municipality of Scido (province of Reggio Calabria, Calabria Region, Southern Italy) (on the left) and the orthomosaic (on the right)

2.2 Laser scanning lidar

For this study, three-dimensional survey data were acquired with the Leica BLK360 terrestrial laser scanner (Fig. 3). The instrument records the geometry of surrounding structures by emitting laser pulses and calculating the travel time of their reflections, thereby determining the spatial coordinates of each measured point. The resulting dataset forms a point cloud in which every point is defined by x, y, and z values. The BLK360 captures up to 360,000 points per second across a horizontal field of 360°, and a vertical field of 300°. Its measurement precision is approximately ± 8 mm at a range of 20 m and improves to ± 6 mm at 10 m, with a maximum scanning distance of 60 m. Raw scan data are saved to the device's internal memory and subsequently managed with the Leica FIELD 360 mobile application, which allows initial organization and coarse alignment of individual scans. Final registration is performed in Leica Cyclone REGISTER 360 (BLK Edition), where automatic alignment supported by the VIS (Visual Inertial System) is refined manually to improve consistency and accuracy. The registered point cloud is then exported in RCP format and processed in Autodesk ReCap Pro to remove noise, segment regions, and optimize the dataset. The prepared project is finally imported into Autodesk REVIT, where the point cloud serves as a spatial reference for constructing the BIM.

2.3 UAV survey and image data processing

The UAV surveys were performed using the Zenmuse L1 mounted on the quadcopter DJI Matrice 300 RTK (DJI Ltd., Shenzhen, China) (Fig. 4). The L1 module is formed by three different sensors: (i) a Livox LiDAR sensor with a class 1 laser and a field of view (FOV) of 70.4°x 77.2° (horizontal x vertical), 480,000 points emitted per second up to a maximum distance of 450 m; (ii) a 1-inch 20 megapixel CMOS sensor RGB camera, synchronized to LiDAR capture; and (iii) a high precision inertial measurement unit (IMU) to monitor the flight parameters (pitch, roll, and yaw). The survey was performed in semi-automatic mode, flying with a speed of 2.5 m/s of speed and 80% of side and forward overlap respectively. Data was acquired at 30 m a.g.l. with a ground sampling distance (GSD) of 1.5 cm.

Fig. 3 Leica BLK360 terrestrial laser scanner (TLS) used for the survey

Fig. 4 Uncrewed Aerial Vehicle (UAV) DJI Matrice 300 RTK used for the survey

The accurate georeferencing of the data was obtained by using the D-RTK 2 Mobile Station. The sensor supports up to 3 returns enabling the acquisition of colored three-dimensional point clouds through the utilization of an RGB 20-megapixel camera. The RGB-colored point cloud was obtained by processing raw data through the proprietary software DJI Terra able to convert the 3D point clouds in the open format *. las [37].

2.4 BIM model

Several site inspections were conducted to document the building's existent condition, and to acquire the information needed for BIM construction. During the walkthroughs, visible construction materials and finishes were identified. For invisible materials, details were required from the facility stakeholders such as walls properties, pavement lavers, ceiling systems, etc. Consequently, the geometric accuracy of the model was ensured, together the visual checks the point cloud derived from the RCP file generated in Autodesk Recap Pro, supplemented by floor-level imagery captured with the UAV. The model comprehensively represented all structural and architectural elements, including the foundation, steel and concrete frames, walls, floor layers and finishes, ceilings, and roofs.

The OM total area includes the following parts (Fig. 5):

- An administrative wing: divided into a renovated old building made of reinforced concrete and including a corridor, a restroom and two offices. A precast newly built part made of precast concrete and included a conference room, two restrooms, a kitchen, a laboratory, and two offices. The floor of the administration is covered with ceramic tiles;
- A production area consists of a large room based on steel columns and delimited by precast concrete walls and an epoxy resin floor;
- An olive oil storage room with Phase Changing Material (PCM) walls for insulation and resin floor;
- A covered external working area supported by precast concrete columns and beams bearing the standing seam roof;
- Both open and covered parking areas, a paved courtyard, and small green spaces surrounding the building;
- The roofs of the OM covered areas are all in metal standing seam, and the external floors are covered either by precast concrete or by gravel.

The model was developed with the necessary geometric and material detail to accurately represent the existing building, rather than conforming to conventional Level of Development (LOD) or Level of Information Need (LOIN)

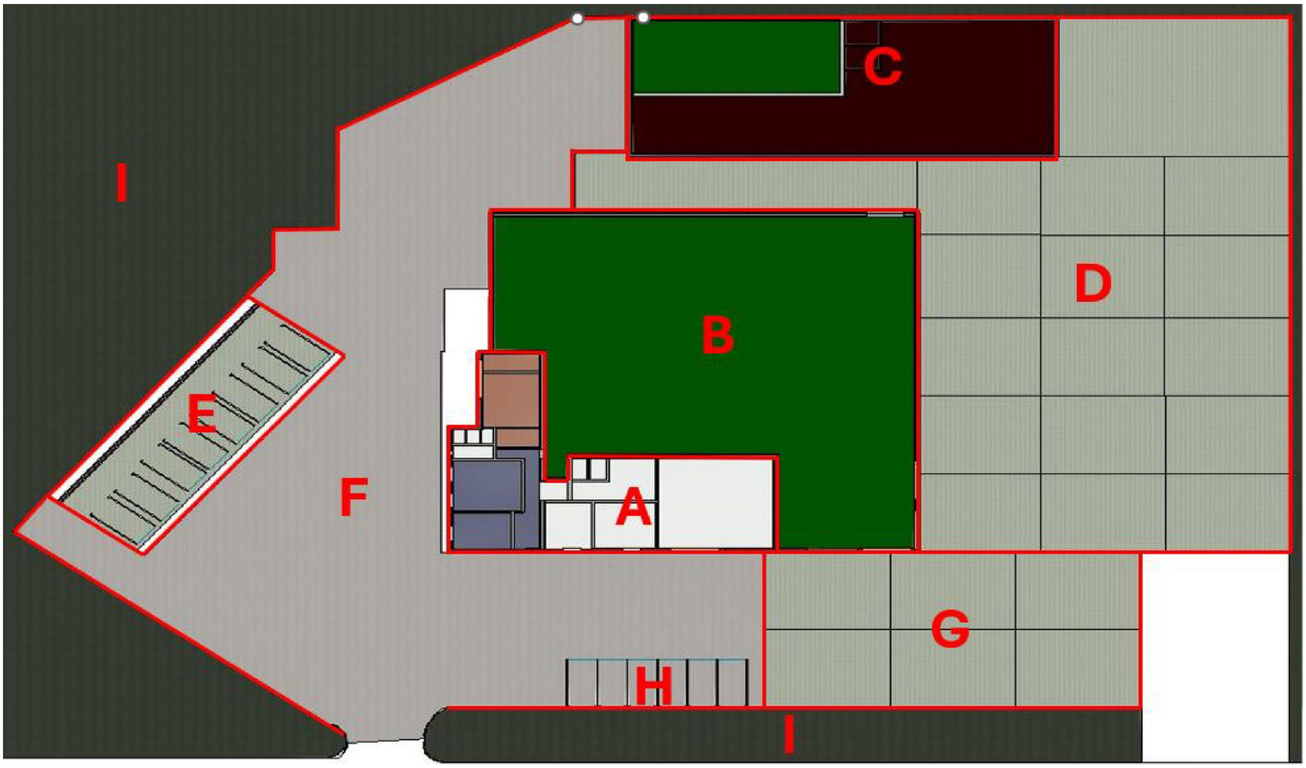

Fig. 5 Different sections of the olive mill (OM): **A** Administration, **B** Production area, **C** Storage room, **D** External working area, **E** Covered parking, **F** Gravel courtyard, **G** Precast courtyard, **H** Open parking, **I** Green spaces

frameworks. Consequently, the required data was exported directly from Autodesk Revit, and the model served as the input database employed in the subsequent environmental simulations.

2.5 Life cycle assessment

2.5.1 Goal and scope

The goal of LCA is to accurately evaluate the environmental impact, with a specific focus on the carbon footprint of the OM structure, using One Click LCA, and based on the BIM model. The study aims to quantify the Global Warming Potential (GWP) in terms of kg CO_{2eq} over the building's lifespan estimated as 50 years, while the functional unit was defined as kg CO_{2eq} per square meter (kg CO_{2eq}/m^2). The assessment follows the EN 15,804 standard, ensuring methodological consistency and reliability. Key data inputs include building materials, energy and water consumption, building area, and lifespan. Additionally, potential reuse or recycling of materials is incorporated where applicable.

2.5.2 System boundaries

This LCA study adopts a cradle-to-grave system boundary, considering the building's entire life cycle including the recycling and recovery of material, when possible. The gain of energy generated from renewable energy sources was also integrated in the analysis. The assessment includes the following stages: material production (A1-A3), construction (A4-A5), use phase (B1-B7), end-of-life (C1-C4), and the possible circular scenarios (D). However, few subphases have been excluded due to data unavailability. A detailed representation of the LCA system boundaries, including all considered subphases, is presented in Fig. 6.

2.5.3 Life cycle inventory assessment (LCInA)

The Life Cycle Inventory (LCIn) of Delia was created first based on the building's available documents and planimetry, real-time photos, and walkthroughs. However, this was not enough to create a holistic representation of the building characteristics. Therefore, One Click LCA plugin was installed in REVIT to allow the automatic transfer of the 3D model to the LCA program cloud. The eventual missing data about the materials, transport, service lifespan, wastage, etc., were completed or adjusted, then the energy and water consumption were retrieved from the bills and inserted into the project. The input data that served to conduct the LCA is summarized in Fig. 7.

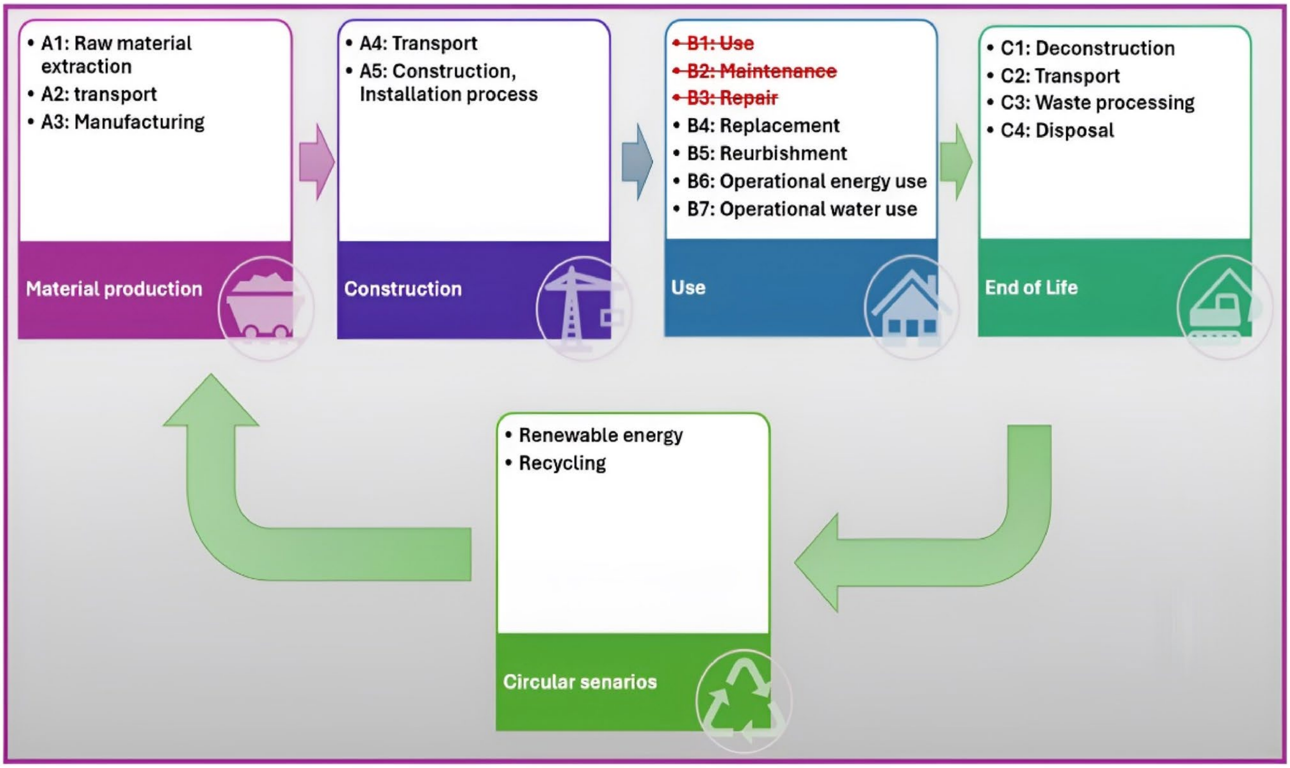

Fig. 6 Life Cycle system Boundaries of the olive mill (OM) Delia

2.5.4 Life cycle impact assessment (LCImA)

The evaluation of the environmental impacts associated with each life cycle stage was carried out following the EN 15,804 + A2 standard. The embodied carbon performance of the OM was studied and the impact category selected as reference is the total GWP measured in $kgCO_{2eq}$.

2.6 Microclimate assessment

The microclimate analysis in this study was conducted by means of ENVI-met; a modeling software designed to simulate urban microclimate conditions. The interaction between buildings, plants, pavements and the atmosphere is analyzed by combining fluid dynamics, thermodynamics, and radiation exchange, to assess important characteristics such as air temperature, humidity, wind patterns, and thermal comfort indices. Research on urban heat islands, green infrastructure, and pedestrian comfort has made considerable use of ENVI-met capacity to predict complex urban geometries and vegetation impacts [38–41]. This reflects the choice of this program to conduct the analysis.

In this study, the microclimate of the OM analysis considers the exterior landscape, infrastructure and vegetation, which is characterized predominantly by olive trees, precast concrete pavement, and gravel pavement surrounding the OM structure. The simulation incorporated 3D modeling of the building and exteriors to point out the Heat Island Effect. A new model in ENVI-met that accurately replicates the one created in REVIT. The model encompasses the walls, roofs, pavements, and soil materials, and the dispersed trees in the external part of the OM with all their characteristics specified in the software (emission, absorption, conduction, albedo, evapotranspiration, etc.).(Fig. 8).

Moreover, fundamental meteorological data namely: temperature, humidity, and wind speed of the location were retrieved from the open source “LadyBug Tool" [42]. Simulations were conducted for three peak heat hours (12:00, 14:00, and 16:00) of a typical hot summer day (29 July 2024), in which the air temperature reached a maximum of about 35 °C (Fig. 9). The selection of this specific day, characterized by high direct solar radiation, facilitated a more robust analysis of microclimatic dynamics during hot weather conditions under a clear sky.

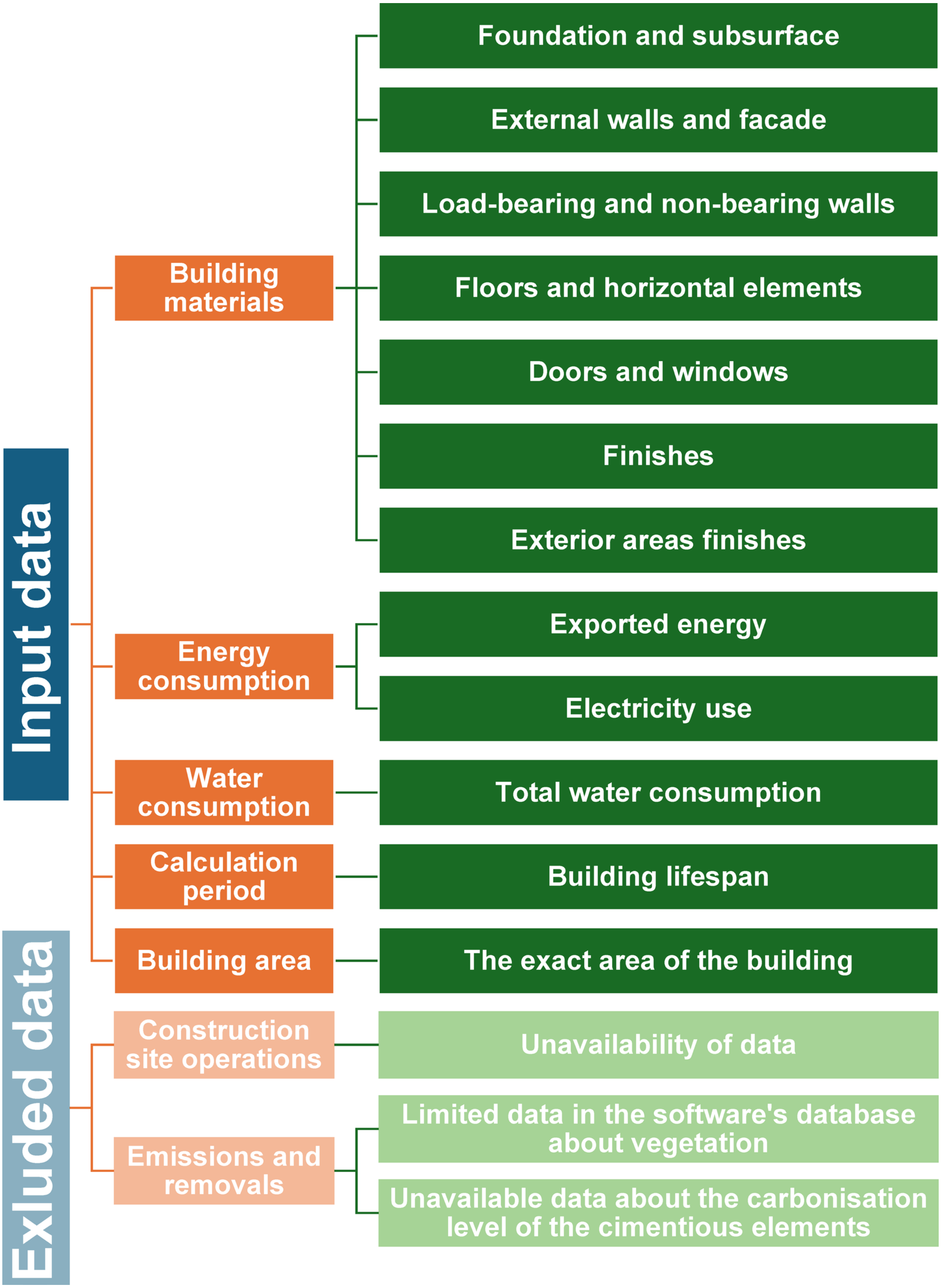

Fig. 7 Summary of data input in One Click LCA program

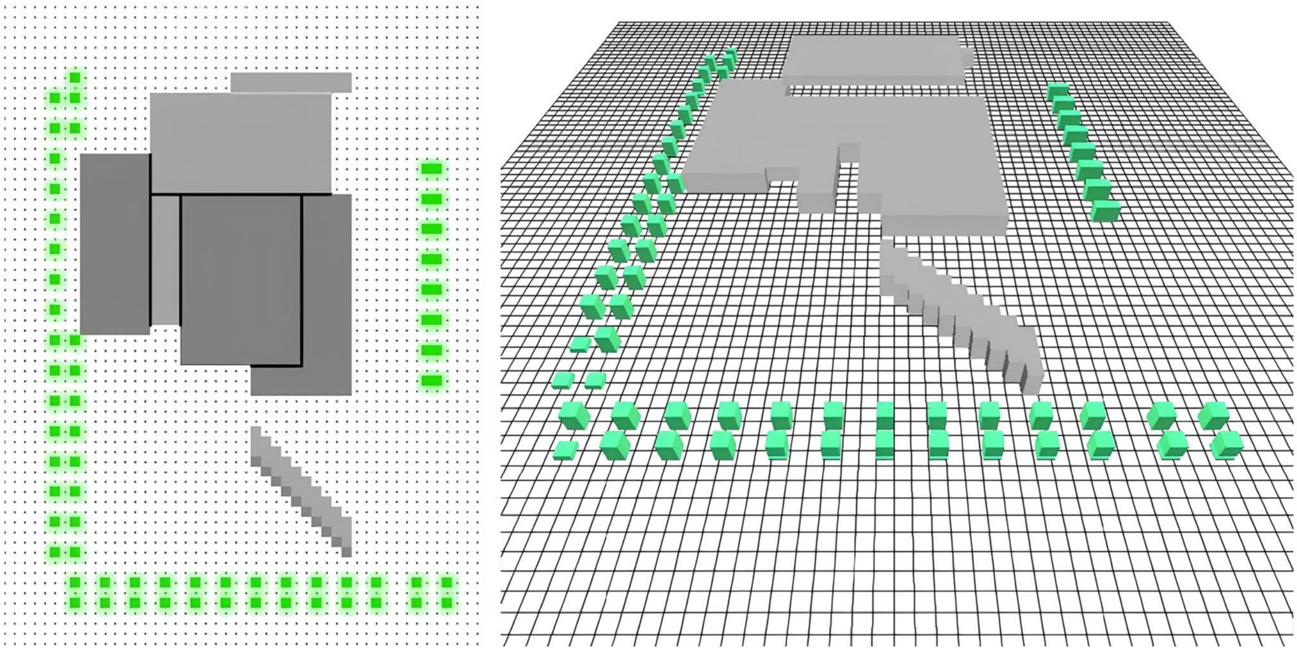

Fig. 8 Olive Mill (OM) model on ENVI_met: 2D (left) and 3D (right) representations

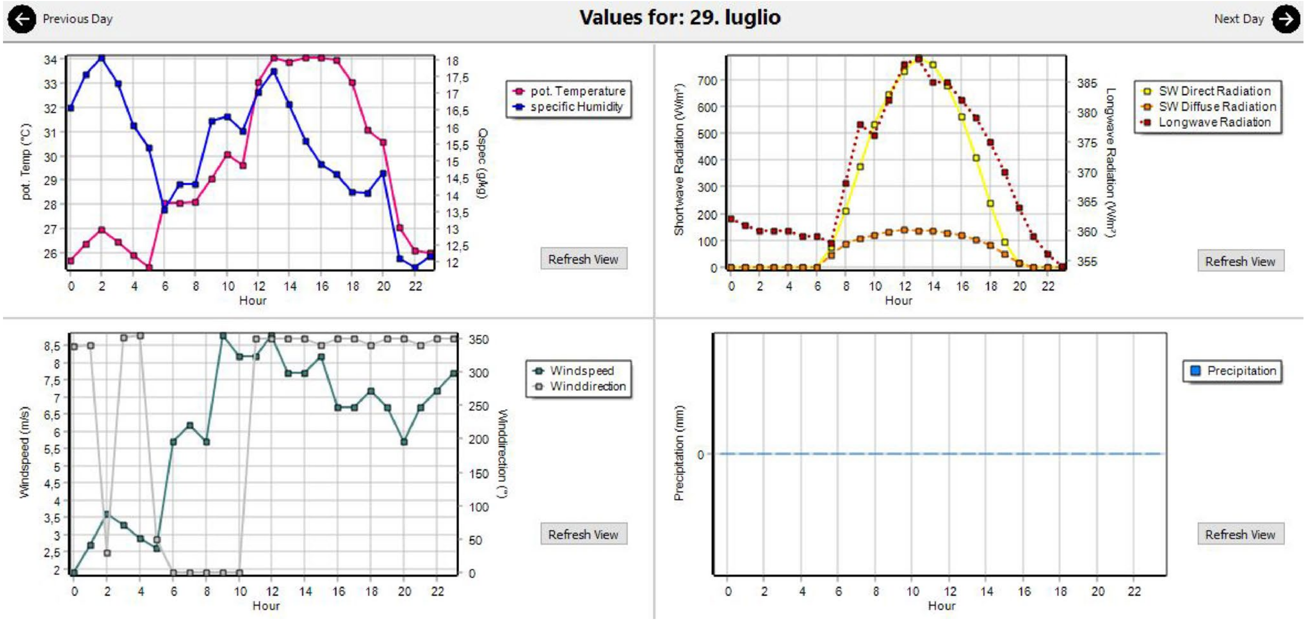

Fig. 9 Meteorological data of the selected day for the microclimate simulation: Temperature and related humidity (up-left), Radiation (up-right), wind speed (bottom left)

3 Results

3.1 Building information model (BIM) of the olive mill (OM)

The BIM model of Delia is shown in Figs. 10 and 11, and 12, showing the different building areas described in the methodology section. This model helped conduct the different building evaluations in this study, because it provides detailed information on building components and material assemblies, including wall and pavement stratifications (e.g., PCM layers, epoxy pavements underlaid with quartz), as well as ceilings, fenestration, and door systems—the BIM model serves as a comprehensive data source for subsequent analyses. Figure 13 presents 3D visualizations of the building interior. Notably, material quantities, dimensions,

Fig. 10 Building Information Model (BIM) of the olive mill (OM) Delia: entrance view

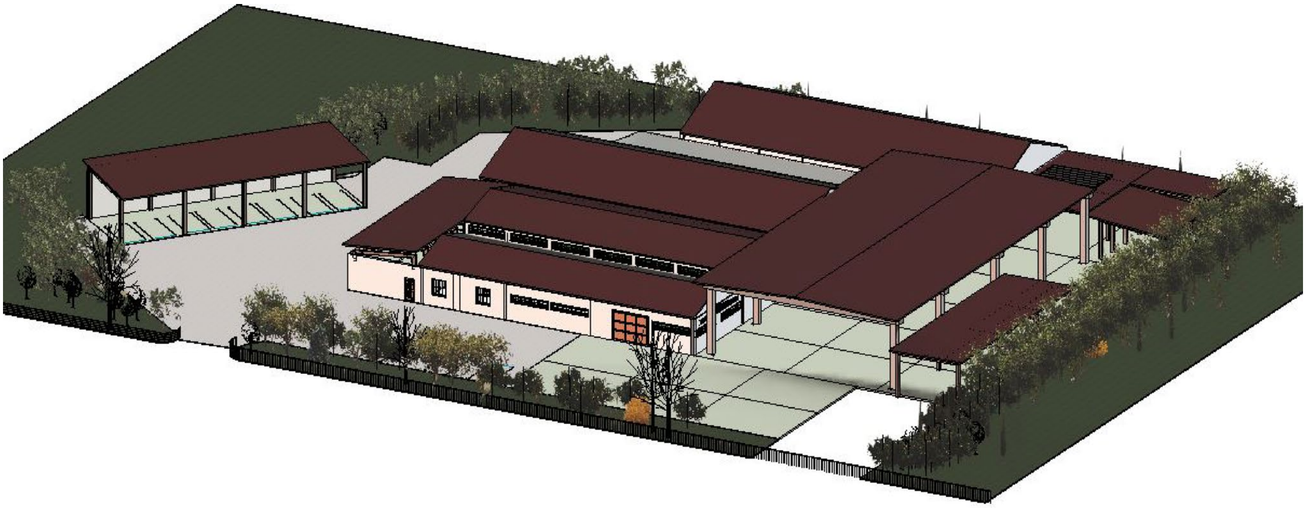

Fig. 11 Building Information Model (BIM) of the olive mill (OM): right side view

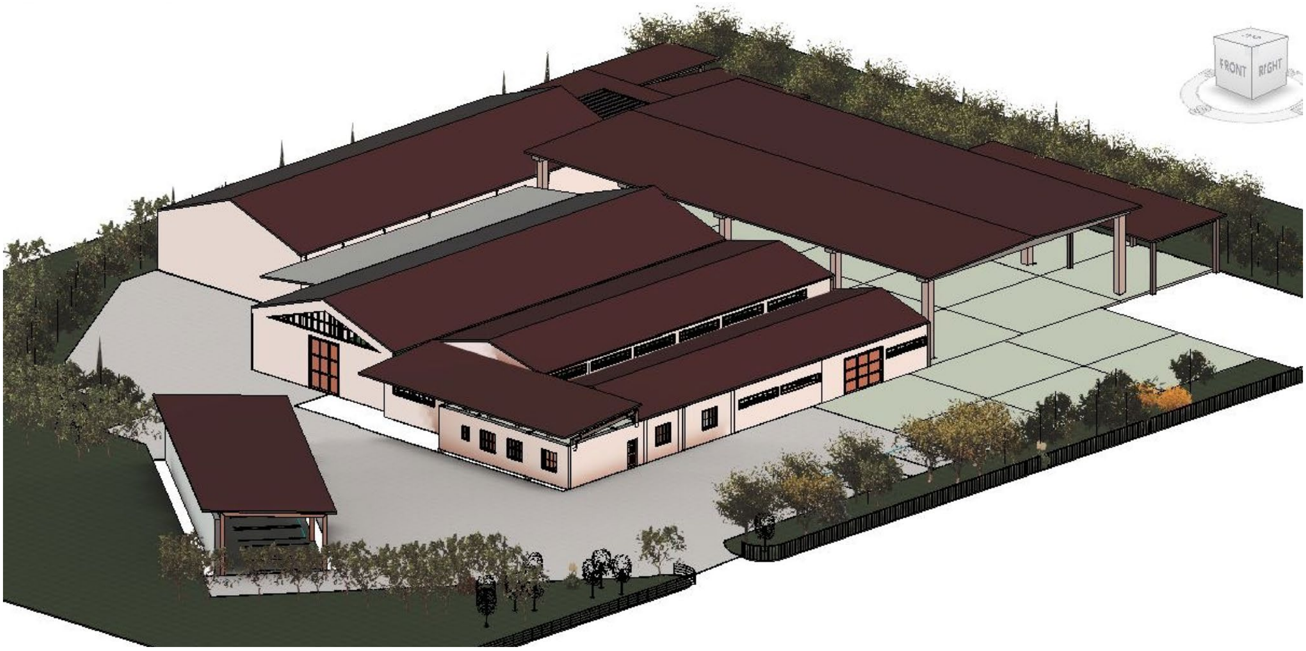

Fig. 12 Building Information Model (BIM) of the olive mill (OM): left side view

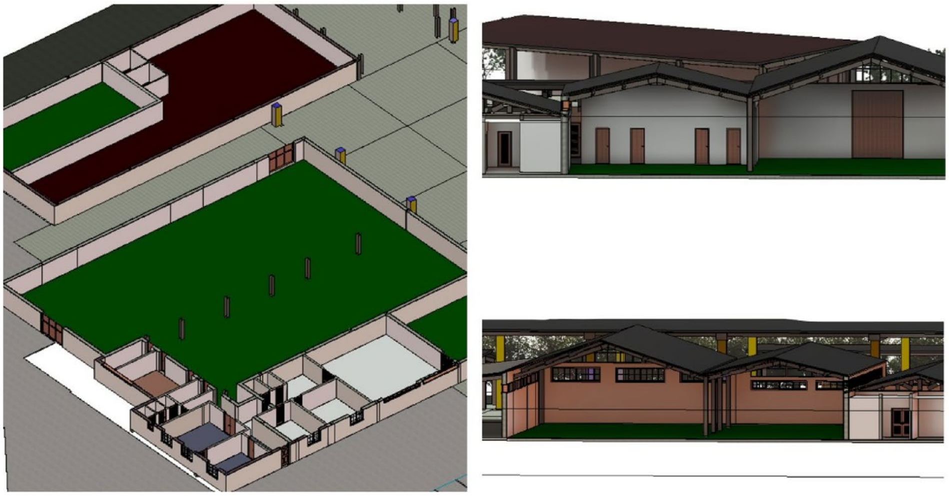

Fig. 13 Building Information Model (BIM) of the olive mill (OM): Interior views

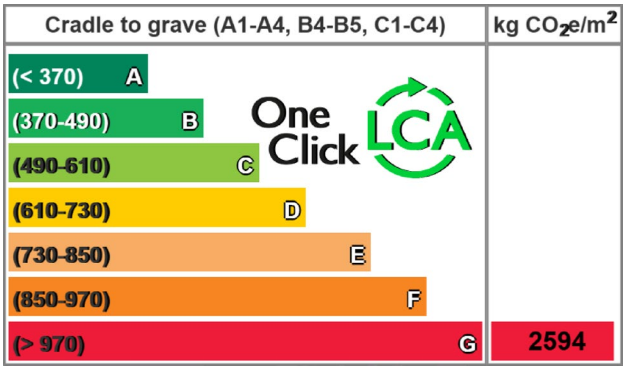

Fig. 14 Cradle to grave embodied carbon benchmark

and geometric attributes are automatically exported from Revit to One Click LCA via a dedicated plugin to facilitate the LCA. For microclimate simulations, the BIM model can alternatively be transferred to ENVI-met through an intermediary platform such as QGIS. The evaluations results and conclusions were also registered within the model's files to be taken into account during future possible extensions or renovations of the building. It is crucial to underscore that this model facilitates a comprehensive environmental evaluation of the building's present performance, while also serving as a robust decision-making tool for assessing the implications of any prospective design alterations or retrofitting interventions.

3.2 Life cycle assessment (LCA)

The LCA of the OM revealed that the embodied carbon estimated from the construction phase until the end of life (from cradle to grave) is high in comparison to Italy's all building types by a value of 2594 kg CO_{2eq}/m^2. Based on established benchmarks for embodied carbon classification, the OM falls within Class G (as illustrated in Fig. 14), representing the highest emissions category.

In more detail, 88% of the total embedded carbon in the structure comes from the material production stage (A1-A3), followed by the use phase (B4-B5) by 9%, then by the transport of material and waste by 1% each. The horizontal structures including beams, floors and roofs count for the highest elements to embed carbon during the A1-A3 stage (Fig. 15).

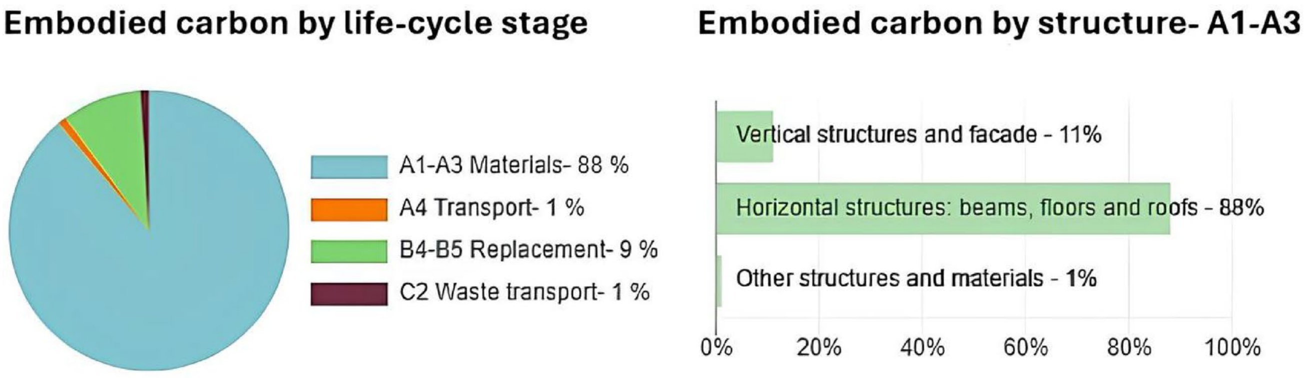

Fig. 15 Embodied Carbon by life-cycle stage and by structure

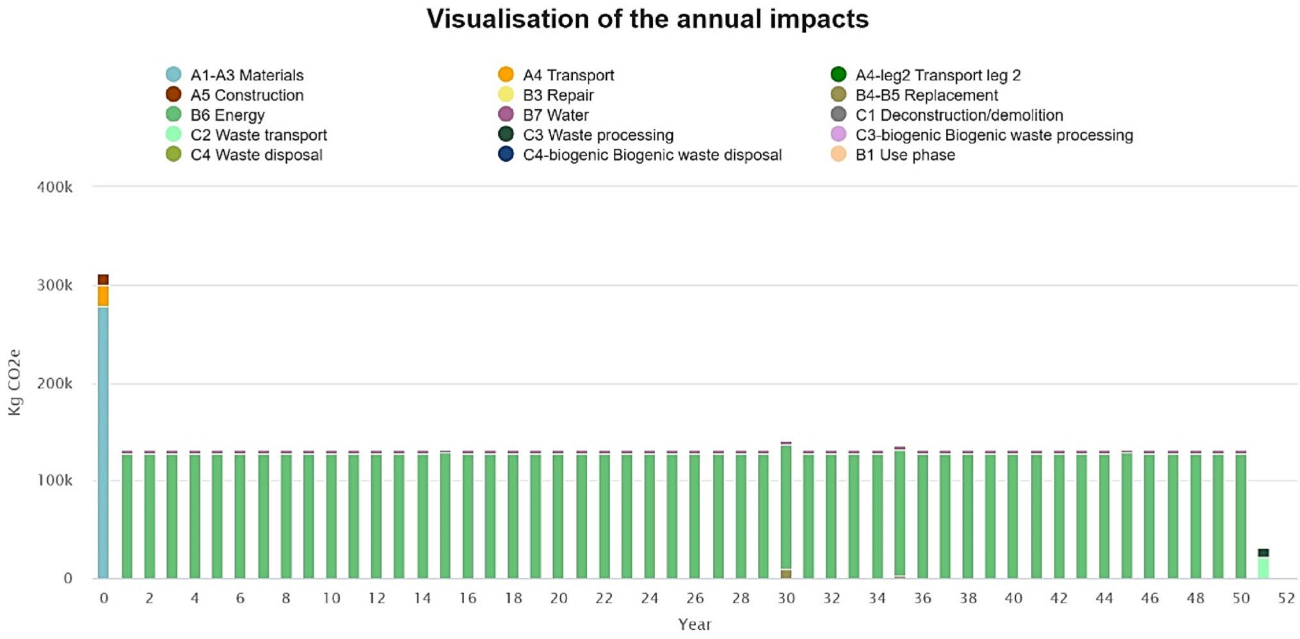

Fig. 16 Global Warming Potential (GWP) by building life cycle stages throughout the building's lifespan

Regarding the GWP impact, its estimation from cradle to cradle was about 7,011,470.39 kg $CO_{2_{eq}}$ over the building's lifespan. By breaking down further, the operational energy consumption (B6: Energy use) was the dominant contributor, accounting for 91.16% of total emissions. This was followed by material extraction, production, and transportation (A1-A3: 3.96%) and water consumption (3.86%), as illustrated in Fig. 16.

Among structural elements, the ground floor slab exhibited the highest environmental impact due to its substantial material volume. This was followed by steel frames, which contributed significantly to emissions owing to their energy-intensive production processes and heavy reliance on fossil fuels.

3.3 Microclimate assessment

The microclimate assessment of the OM aims to better understand the micro-environmental behavior of around the building. The simulation was carried out considering a typical hot summer day as in the area of Scido municipality, in which the air temperature is usually above 30 °C and can sometimes reach 40 °C. Simulations were run at three of the hottest hours in the day: 12 pm, 2 pm, and 4 pm, to inspect the distribution of heat, humidity and air movement in the area. The OM is housed in a compact, large building with impervious, heat-absorbing surfaces, featuring dense concrete walls surrounded by concrete pavements. Adjacent to the structure, a series of olive trees are planted: they stand close to the western wall, approximately 25 m from the southern side and 10 m from the eastern side. While olive trees can provide localized cooling through evapotranspiration and ground shading, their thermal impact on the building envelope is negligible due to their far placement. Instead, their contribution to reducing heat absorption and reflection from paved surfaces affects a broader microclimate. In fact, the analysis of potential air temperature, relative humidity, and wind speed accentuates this reasoning and shows a strong correlation between building morphology, orientation, wind movement, and thermal distribution.

Figures 17 and 18, and 19 show that at the simulation times, the wind speed varies from 0.5 m/s to 2.5 m/s with slightly stronger airflows in peripheral open zones. The air temperature ranges from 32.04 °C to 35.26 °C around the building, which is out of the comfortable range for a human body identified as between 9 °C and 26 °C. With high solar exposure and absence of canopied trees nearby, the south and southeast sides of the building seem to be the hottest, coinciding with reduced humidity. Indeed, since no additional moisture sources are available, the accumulated heat raises air temperature making it more able to hold water vapor, resulting in a decrease in relative humidity. The hot dry air is emphasized by the low wind movement pushing the heat to stagnate and form a heat island over the building at pedestrian level (from 1.4 m to 2 m height). Consequently, this heat pattern reflects a lack of ventilation around and inside the structure, especially from the southern side, which could be translated by the presence of humidity indoors in cold weather, and extreme heat in summer.

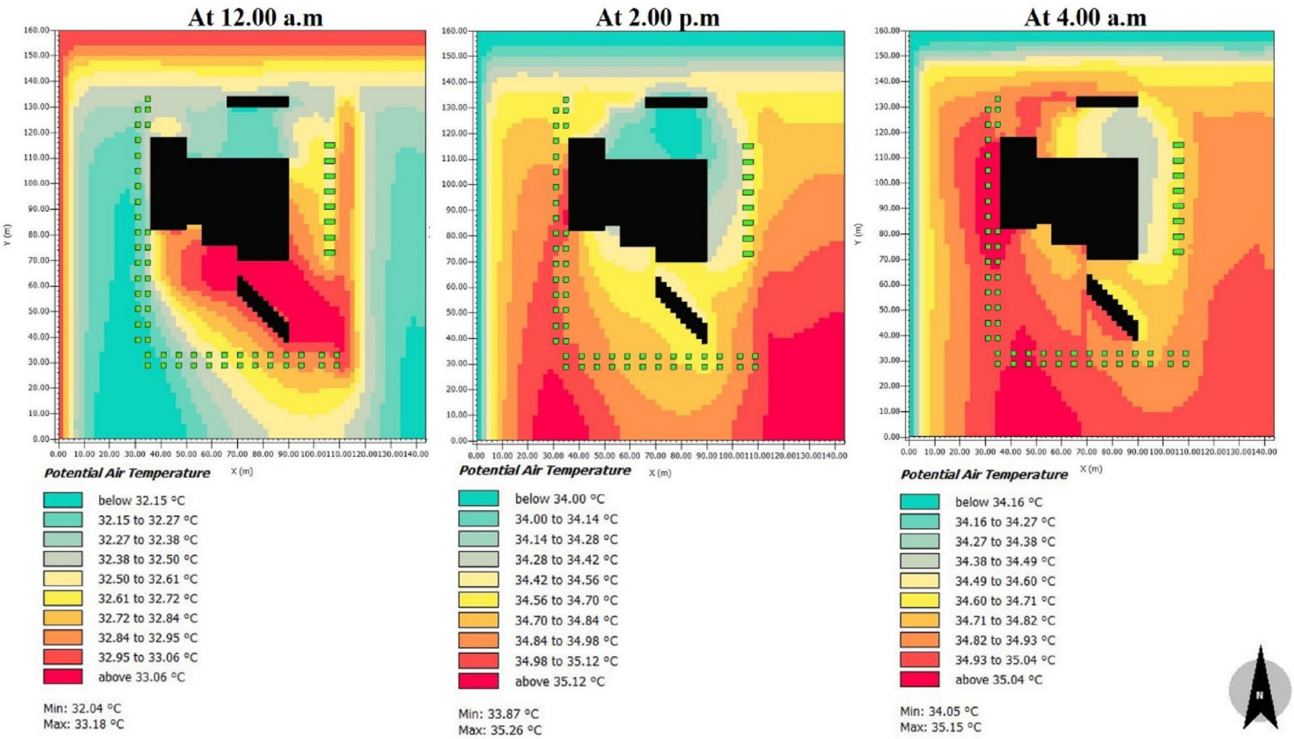

Fig. 17 Distribution maps of Potential Air Temperature at respectively 12 pm, 2 pm, and 4 pm in the olive mill (OM) “Delia”

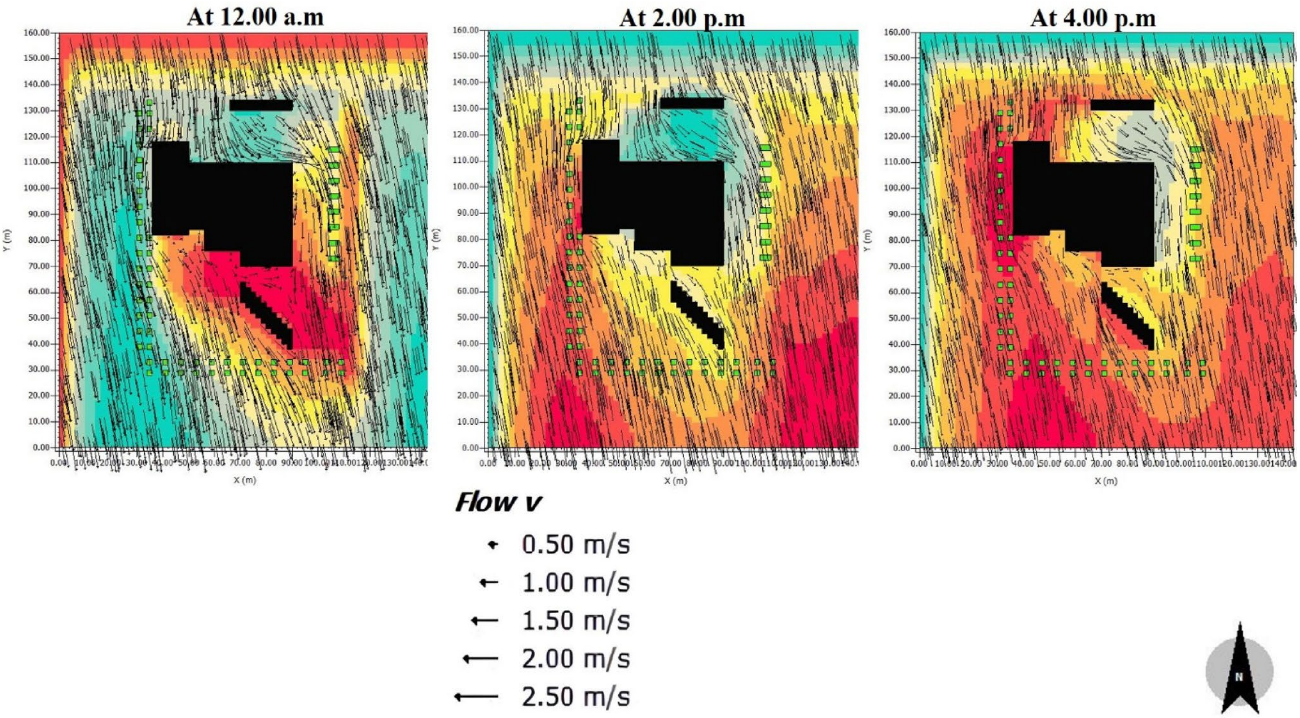

Fig. 18 Distribution maps of wind speed at respectively 12 pm, 2 pm, and 4 pm in the olive mill (OM) “Delia”

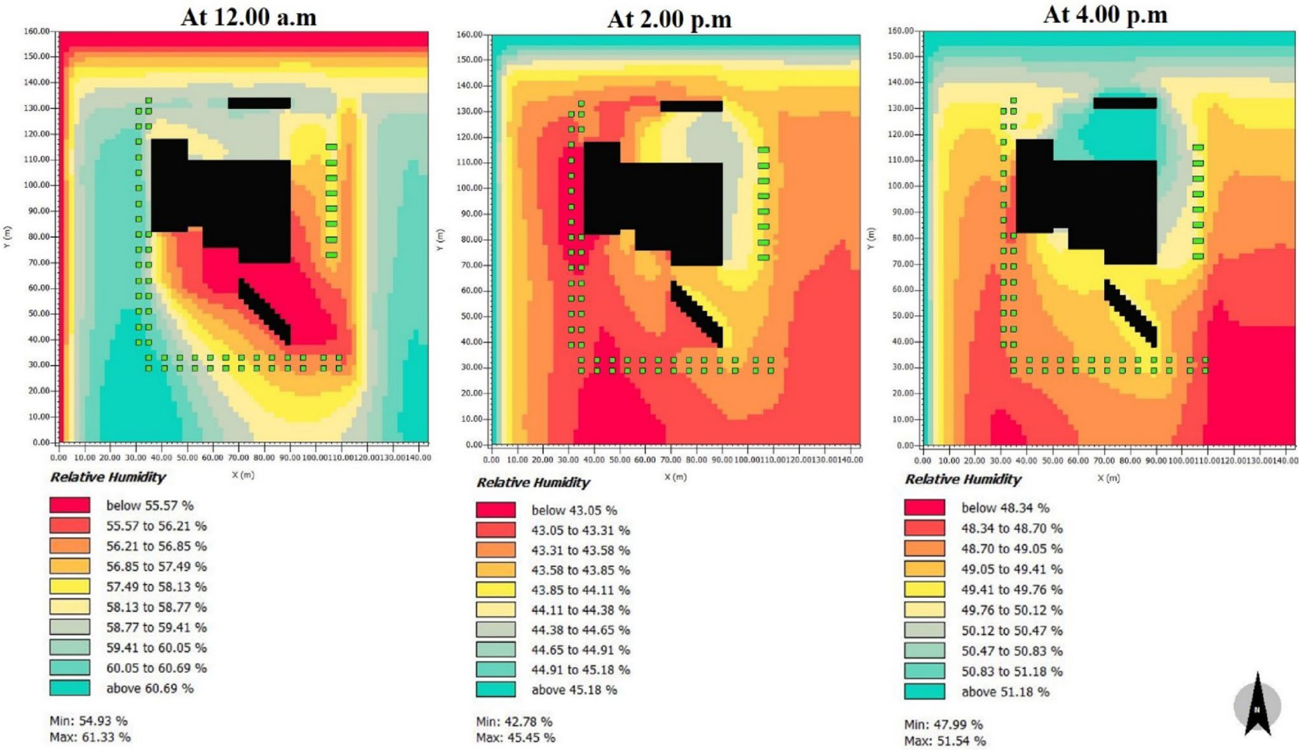

Fig. 19 Distribution maps of Relative Humidity at respectively 12 pm, 2 pm, and 4 pm in the olive mill (OM) "Delia"

4 Discussion

This study utilized UAV imagery and laser scanning to capture real-time exterior and interior characteristics of an OM in southern Italy. These technologies have proven highly effective in the construction industry, both for monitoring ongoing construction progress and for generating accurate virtual building planimetries in cases where original documentation is unavailable. In fact, the OM in this case study has undertaken several modifications and renovations without traceability since it has been operational to produce olive oil. Inside the building, some rooms have been connected, and some others have been separated. Furthermore, standing seam tile roofs have been extended to cover all the administration, the indoor and the outdoor operational areas. The images obtained of the structure helped build the BIM model of the OM based on which environmental and microclimate analysis were conducted. This framework proved efficient in rapidly generating the necessary results and highlighting the growing need to assess the sustainability and environmental impact of food-related buildings, which are expanding quickly due to rising population demands. Notably, the Mediterranean region is home to most OM structures, which are responsible for producing approximately 90% of the world's olive oil supply and providing employment for thousands of workers. It is essential to expand environmental assessments beyond production and processing to include the evaluation of structural performance, particularly from a social perspective that emphasizes the necessity of ensuring a safe, comfortable, and convenient workplace for workers, as well as aligning more effectively with sustainability pillars and climate change adaptation. Moreover, emerging technologies are increasingly supporting environmental research and assessment such the case study in this research by transferring the BIM model to LCA tool (One Click LCA) which allows to retrieve building data automatically. Regarding ENVI-met, importing the BIM model generated in Revit requires several intermediate steps. The Revit model is first exported as a CAD file and subsequently imported into QGIS, where the ENVI-met plugin enables the execution of microclimate simulations. However, when detailed open-source data on vegetation and soil conditions are lacking, particularly precise characteristics of every individual tree, this procedure becomes insufficient for generating a reliable microclimate model. In such cases, the missing information must be entered manually, a process that becomes increasingly complex in areas with dense vegetation. Consequently, comprehensive and publicly accessible geospatial datasets on urban vegetation and soil characteristics are essential for conducting robust analyses related to climate-change adaptation and resilience.

In the same context of this study, several environmental evaluations including LCAs have been conducted on OMs, however, they focus on agricultural, transformation, transportation, and waste management phases [43]. Which confirms what was reported in this and other research that the building performance in food industry still passes unnoticed [44, 45]. Herein this work, the LCA analysis concludes that OMs could be as much impactful as many other types of buildings, and that including the emissions related to the building and its maintenance in environmental evaluations gives a wholistic insight on the real impact of OMs as the construction of the building considerably consumes resources and impacts the climate as much as the agricultural or the production phases. This kind of study might aid in the development of a database tailored to the worldwide impact of the olive industry, which would assist in defining the sector's weight on climate change, and establishing a benchmark beyond which an OM would be classified highly polluting. It is very important to highlight that a huge number of OMs were constructed so many years ago, using heavy cast in place materials such as reinforced concrete (the case of Delia). Furthermore, during that period, understanding of climate change adaptation and sustainability was constrained, rendering the design of environmentally friendly a secondary consideration.

To extend the assessment of the OM building performance, a microclimate analysis was carried out on a typical hot summer day. The study aims to evaluate the heat island effect impacting thermal comfort in the facility, in very hot weather conditions. Despite the suspension of olive oil production during summer, this period is dedicated to building maintenance and cleaning of the process machinery, therefore, it requires the presence of workers. Actually, this kind of analysis is usually conducted over cities and neighborhoods encompassing a group of buildings, to compare different scenarios of urban designs. Some studies succeeded in highlighting the hotspots in study areas and suggesting solutions capable of reducing air temperature from 0.5 to 1.5 °C, such adding vegetation or water fountains [46, 47]. Nevertheless, this work focuses on the microclimate analysis of a complex building, placed in the suburbs of a small city. In fact, the study shows that the design of the building accentuates the formation of heat islands around it, especially in its southern side. This zone is the place where many logistical activities are done such as evacuating the solid wastes, freighting the oil from the storage room, or handling the process machinery. Moreover, during the olive campaign that figures out many hot days, the visitors number to the company may reach over 50 a day. Its relatively large surface is completely paved by gravel or concrete, which, in conjunction with its south exposure, intensifies the heat concentration which makes it uncomfortable to work in the area. Furthermore, it was the reason why a PCM was added to the walls of the storage room, to emphasize the insulation. Yet, the administration and the operational areas are built in a single complex that is no higher than 3 to 4 m, which prevents air corridors, and accentuates the air stagnation in some regions surrounding the buildings.

The integration of LCA and microclimate analysis reveals critical trade-offs in sustainable design. For instance, the use of outdoor concrete pavement contributes to higher embodied carbon while simultaneously exacerbating thermal discomfort through the formation of localized hotspots. Conversely, strategic design choices, such as building orientation, vegetation placement, and material selection, play a pivotal role in mitigating these effects and should be prioritized during the early design phase or renovations.

Notably, this OM was previously evaluated using a green building certification tool [44], where it demonstrated strong performance in key categories such as energy efficiency, innovation, and waste management. However, while the green building tool assessment concluded the heat island performance as very effective, our microclimate analysis indicates potential shortcomings in thermal performance. This discrepancy underscores the importance of complementing evaluation tools with exhaustive simulations to optimize building and urban design for thermal comfort and sustainability.

In summary, the integration of multiple technologies, such as UAV imagery, laser scanning, and BIM, has demonstrated considerable effectiveness in generating accurate digital twins of existing structures. Furthermore, the development of software plugins has significantly facilitated interoperability between these technologies and various structural assessment tools, streamlining the evaluation process.

This study proposes a comprehensive framework aimed at simplifying and enhancing the assessment of existing buildings. In particular, it emphasizes the urgent need to evaluate the structural performance of aging buildings, which are prevalent throughout the Mediterranean region, including heritage structures such as OMs. Given the growing necessity for adaptation to climate change in the construction sector, such evaluations are critical for identifying structural vulnerabilities. Addressing these weaknesses can inform targeted interventions that improve building resilience, enhance sustainability, and support long-term adaptation strategies to face evolving environmental challenges.

5 Conclusions

This study presents a complete framework for evaluating the environmental and microclimate performance of buildings in the agri-food field, namely an OM, thereby addressing a neglected aspect of food manufacturing chain. The proposed methodology integrates UAV photogrammetry, laser scanning, and BIM modeling with LCA and microclimate simulations, providing a comprehensive framework for the analysis of food-related industrial structures. The findings demonstrate that the evaluated olive mill structure generates significant embodied emissions and contributes to local heat island effects, highlighting the significance of material selection, design methodologies, and landscape in enhancing thermal comfort and sustainability. The contrast with LEED assessments underscores inconsistencies between certification tools and detailed simulations, emphasizing the necessity of incorporating digital modeling into green building assessments. Finally, this framework can be extended to various facility types within the agri-food sector, contributing to the development of a comprehensive database for establishing environmental benchmarks and classifying buildings according to their performance. Moreover, the exploration of advanced technologies such as digital twins for real-time monitoring and assessment represents a promising direction for understanding the interactions among buildings, workers, and products in both indoor and outdoor environments within the sector.

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Data availability Data will be made available on request.

Declarations

Conflict of interest The authors declare no competing interests.

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